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Citizen science reveals the present range and a potential native predator of the invasive slug *Limax maximus* Linnæus, 1758 in Hokkaido, Japan

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Abstract

The giant garden slug *Limax maximus* Linnæus, 1758 (Limacidae, Pulmonata) is considered one of the most widely spread terrestrial molluscs in the world and is a formidable pest of agricultural and horticultural crops. This slug was recently introduced to Japan, where its population is now rapidly increasing and spreading. A naturalised population of *L. maximus* was first discovered in Hokkaido, Japan, in 2012 in the isolated natural forest of Maruyama Forest Park in Sapporo City, and the species has become common in this area. In the present study, we investigated observations of *L. maximus* reported by ordinary citizens acting as "citizen scientists" to assess the recent expansion of this invasive slug. We posted an announcement in the local newspaper requesting reports of the occurrence of *L. maximus* via e-mail and analysed 38 observations provided by local citizens. As a result of these reports, 16 naturalised populations of *L. maximus* were detected in Hokkaido, several of which were quite far from the original population in Sapporo City. Moreover, a terrestrial macrophagous leech, *Orobdella kawakatsuorum* Richardson, 1975 (Arhynchobdellida, Orobdellidae), is reported as a potential native predator of *L. maximus* for the first time.

Key words: agricultural pest, Gastropoda, predator-prey interaction, Hokkaido Island

Introduction

Invasive terrestrial mollusc species have been recognized as some of the most significant and persistent threats to native ecosystems and agriculture (e.g., Lowe et al. 2000; Barker 2002; Mito and Uesugi 2004). The giant garden slug, *Limax maximus* Linnæus, 1758 (Limacidae, Pulmonata), is one of these species. This slug is considered one of the most aggressive terrestrial molluscs in the world and is a formidable pest of horticultural and agricultural crops (e.g., Barker and McGhie 1984; Barker 1999). *L. maximus* is native to Europe and Asia Minor but is now widespread globally, being found in North America, South America, North Africa, South Africa, Australia, New Zealand and other regions (Barker and McGhie 1984; Barker 1999; McDonnell et al. 2009). This slug was recently introduced to Japan, and its population is now increasing rapidly and spreading throughout the country; it has been observed on two main islands, Honshu Island (Ibaraki, Nagano and Fukushima prefectures; Hasegawa et al. 2009; Iijima et al. 2013) and Hokkaido Island (Iijima et al. 2013; Morii et al. 2016).

A naturalised population of *L. maximus* was first discovered on Hokkaido, Japan in 2012 in the isolated natural forest of Maruyama Forest Park in Sapporo City (#1 in Supplementary material Table S1 and Figure 1; Iijima et al. 2013). The species has now become common in this area (Morii et al. 2016). Y. Morii (YM) investigated personal web sites reporting

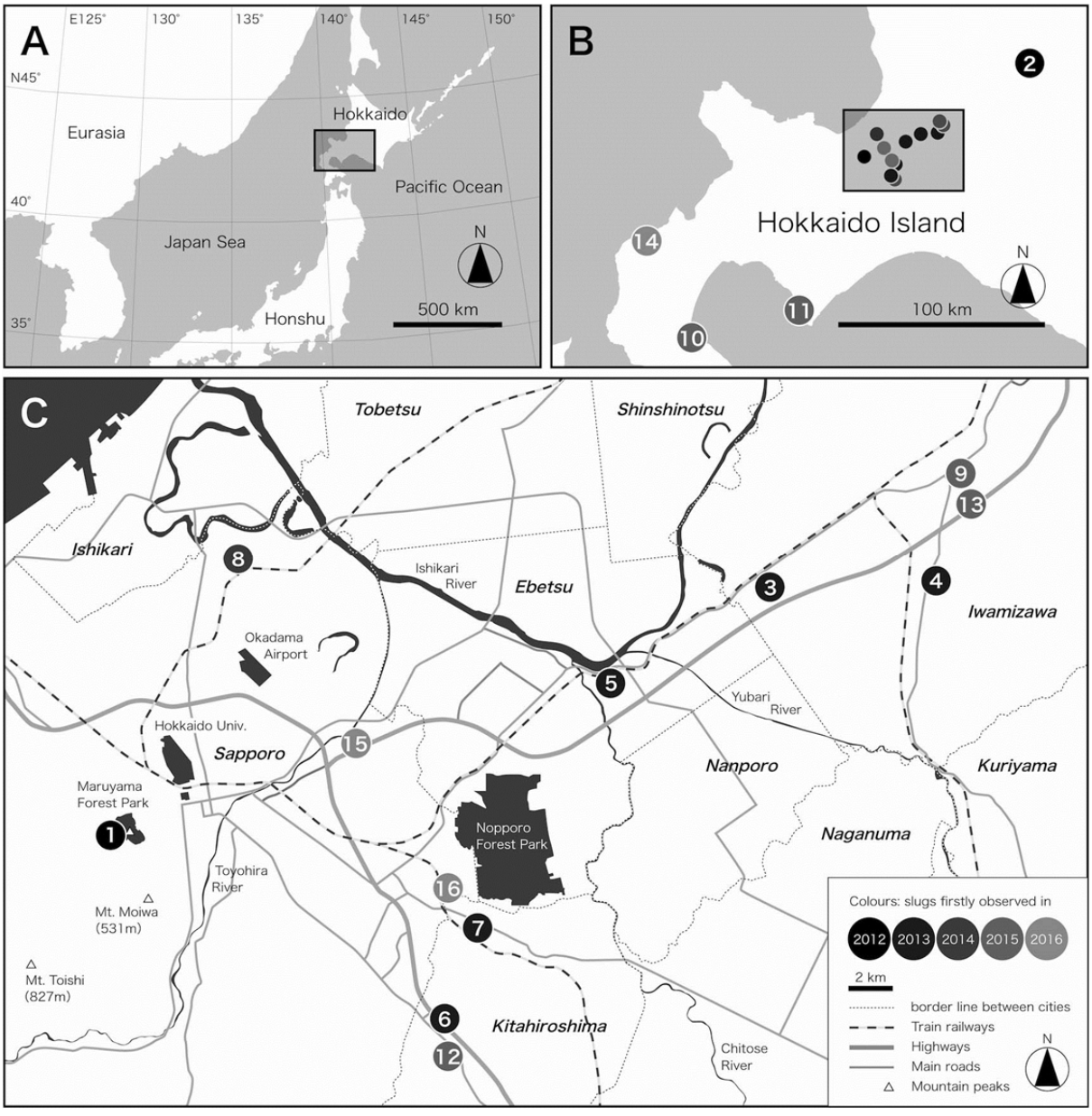

Figure 1. A map of localities where *Limax maximus* was observed by citizen scientists. Numbers correspond to the numbers of the localities provided in Table S1. No new reports have been received since October 2016.

observations of *L. maximus* in Hokkaido, contacted the owners of these web sites and consequently identified another naturalised population in Hokkaido (Ebetsufuto, Ebetsu City; #5 in Table S1 and Figure 1), located 30 km from Maruyama Forest Park, Sapporo City (Morii et al. 2016). This result suggests that data from citizen scientists (Bonney et al. 2009; Silvertown et al. 2011; Worthington et al. 2012) may allow the distribution of this invasive slug to be tracked throughout Hokkaido. In the present study, we investigated observations of *L. maximus* reported by citizens acting as "passive surveillance" (Hester and Cacho 2017) recruited especially through a local newspaper and a television programme in Hokkaido, and assessed the recent expansion of this invasive species. Our collaboration with the citizen scientists revealed a potential predator, indigenous to the island, of this novel invasive slug.

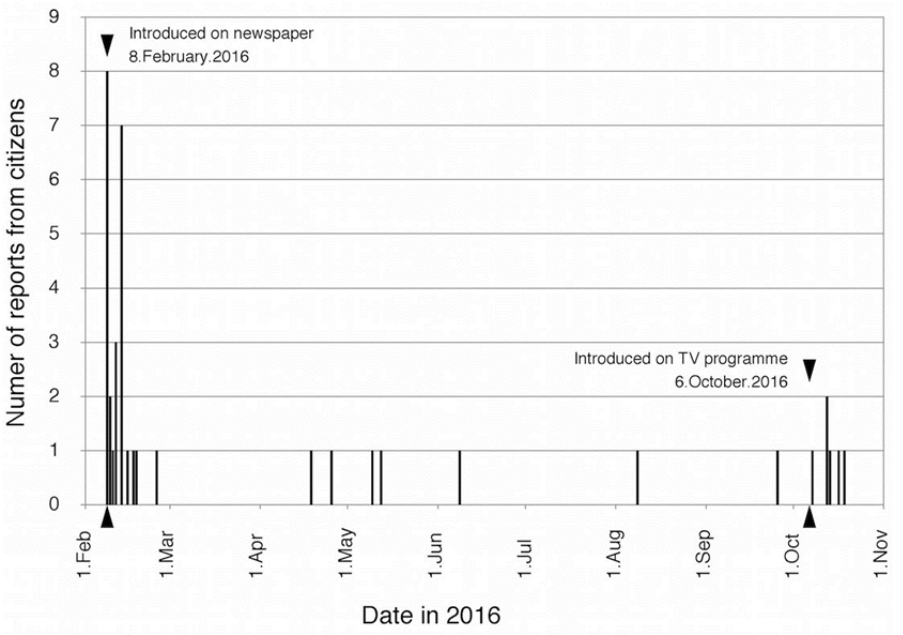

Figure 2. Dates of the occurrence reports of *Limax maximus* by local citizens.

Methods and findings

On 8 February 2016, YM placed an advertisement in the local newspaper in Hokkaido (Hokkaido Simbun Press) requesting readers to report observations of *L. maximus* via e-mail. In addition, on 6 October 2016, YM discussed the introduction of this slug to Hokkaido on a local television programme (Hokkaido Cultural Broadcasting Co., Ltd.). A total of 38 observations were reported from 8 February 2016 to 18 October 2016 (Table S1). 32 reports were e-mailed before the introduction on a local television programme, and other 6 were reported after that (Figure 2). Among these observations, 29 reports were accompanied by three pieces of information: 1) a photograph, 2) an exact location, and 3) the date of the observation of the slug. These 29 records were analysed in the present study along with previously published occurrence records for this species (Iijima et al. 2013; Morii et al. 2016) (Table S1; Figure 1).

As a result of these reports, 16 naturalised populations of *L. maximus* were detected in Hokkaido, 14 of which were previously unknown (Table S1; Figure 1; Figure 3). Twelve of the populations were located within a 30 km radius around Sapporo (Figure 1C). However, four sites were quite far from Sapporo and were distant from each other (#2, 10, 11 and 15 in Table 1 and Figure 1). At the Takisato Dam, in Ashibetu (#2 in Table S1 and Figure 1), *L. maximus* was observed within the same year that it was first discovered in Hokkaido (Maruyama Forest Park; #1 in Table S1 and Figure 1). Notably, one of our collaborators reported that one alive *L. maximus* individual was preyed upon by a terrestrial macrophagous leech, *Orobdella kawakatsuorum* Richardson, 1975 (Arhynchobdellida, Orobdellidae) (Figure 4).

Discussion

Our citizen science data for the *L. maximus* populations in Hokkaido demonstrated that this invasive slug has become well established in and around Sapporo City over the last six years. The detection of this species in Sapporo City and adjacent areas over the last six years demonstrates that this invasive slug has become well established in this region. Moreover, recent occurrences at localities approximately 100 km from Sapporo City (#10, 11, and 15 in Figure 1) highlight the continued expansion of the distribution of *L. maximus* on the island. *L. maximus* is capable of living in modified habitats such as parks, gardens and rubbish dumps (Barker 1999; Kozłowski 2012). In addition, this slug is a generalist and may be cannibalistic, and it is known to have damaged agricultural and horticultural products (Barker and McGhie 1984; Barker 1999; Kozłowski 2012). Several observations obtained in this study also indicated that *L. maximus* fed on agricultural products, including cucumber, sweet potato, lettuce and Chinese cabbage (Table S1). Therefore, the populations of *L. maximus* in Hokkaido should be controlled and eradicated.

Figure 3. *Limax maximus* (A–E) and their habitat (F) in Hokkaido. (A) *L. maximus* at Shimamaki (#15 in Table S1 and Figure 1) provided by Ryusei Yamakami; (B) at Sapporo (#8) by Mariko Komori; (C) at Muroran (#11) by Tomoo Naka; (D) at Oomagari, Kitahiroshima (#6) by Toshiyuki Komatsu; (E) at Yakumo (#10) by Kunihiko Hanada; (F) *L. maximus* habitat in Yakumo (#10) by Kunihiko Hanada.

The observation of the macrophagous leech *O. kawakatsuorum* preying on *L. maximus* indicates a potential prey control strategy for this species (Figure 4). *Orobdella* leeches are terrestrial species inhabiting Japan and adjacent regions and are known to feed on earthworms (Nakano 2017). In Hokkaido, the species *O. kawakatsuorum* exhibits a body length of up to approximately 10 cm, and *O. koikei* Nakano, 2012, exhibits a body length of less than 5 cm; only these two species inhabit the island, and they have

Figure 4. The sequence of *Limax maximus* predation by *Orobdella kawakatsuorum*.

been known to occur sympatrically (Nakano 2012). The body size of the invasive slug *L. maximus* have been recorded as up to 20 cm (Kerney and Cameron 1979; Barker 1999); those of the introduced populations in Japan were reported as ~15 cm (Figure 3; Hasegawa et al. 2009; Morii et al. 2016). Therefore, it is possible that *O. kawakatsuorum* could act as a more effective native predator of this invasive species than *O. koikei*. Several large *Orobdella* species are distributed across Honshu, including Ibaraki, Nagano and Fukushima prefectures (Nakano 2017). These species typically exhibit a body length of approximately 10 cm, while one of these species can exceed 20 cm in length. Therefore, ex situ investigations should be conducted to determine whether not only *O. kawakatsuorum* but also other *Orobdella* species can act as novel predators of invasive *L. maximus*.

Citizen science data were shown to be a powerful tool for revealing the current range and a potential native predator of invasive *L. maximus* populations on Hokkaido. Such citizen science data are extremely effective for tracking the expansion of recently introduced species (e.g., Maistrello et al. 2016), such as the invasive slug studied herein. However, it is possible that the distribution of this slug has already expanded more widely than these results suggest, as our occurrence data were generally restricted to the most densely populated areas of Hokkaido. Mass media played an important role in this study, as it allowed us to obtain valuable information from local residents (for a discussion of the effectiveness of mass media in citizen science see van Vliet et al. 2014).

Nearly all the observations were reported shortly after the notice appeared in the local newspaper, but a second peak in submissions was noted in early October 2016 after the broadcast of the television programme (Figure 2). Many studies report using web resources (Sullivan et al. 2009; Silvertown et al. 2011), and additional other multiple kind of mass media simultaneously such as newspapers, television, radio and magazines (Worthington et al. 2012; Goldstein et al. 2014). In contrast, we reached out via a newspaper and a television programme instead of the internet. Therefore, this study indicated the pure impacts of announcement via a newspaper article and a television appearance, and also showed the difficulty of maintaining the passive surveillance survey by citizens and keeping it active.

It is clearly impossible to manage the rise in global issues related to introduced species through the work of scientists alone (Delaney et al. 2008; Crall et al. 2010; Goldstein et al. 2014); a follow-up citizen science survey could contribute to the future containment of all introduced species around the world. *L. maximus* is especially conspicuous species and easy to identify especially in Japan, but this methodology can also be applied to other less noticeable species using photographs as in this study.

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The following supplementary material is available for this article:

Table S1. The reports of *Limax maximus* observed in Hokkaido Island.

This material is available as part of online article from:
http://www.reabic.net/journals/bir/2017/Supplements/BIR_2017_Morii_Nakano_TableS1.xlsx